

Indicators for the condition of estuaries and coastal waters

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Summary

Our main objective in developing this report is to establish a standard set of indicators and monitoring methods to be used in estuaries and coastal waters in Tasmania. Until now, most estuaries and coastal waters in Tasmania have not been monitored in any consistent manner, if at all. Thus the value of these data is greatly reduced because it is not possible to make comparisons over time or between regions.

Hence, the purpose of this report is to provide a simple working document to be used in the monitoring of estuaries and coastal waters around Tasmania. Practical information is provided for a range of parameters, which can be easily applied during the establishment a monitoring program. Recommended methods have been divided, where appropriate, into two groups: (i) simple and inexpensive methods suited to community based monitoring and (ii) more complicated methods requiring some expertise and often external funding.

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Introduction

Objectives

The purpose of this document is to recommend a monitoring program for the condition of estuarine and inshore coastal waters that is relevant to the Tasmanian environment.

The indicators that are recommended for monitoring in Tasmania have been developed by the Tasmanian Coastal, Estuarine and Marine (CEM) Indicators Working Group, which consists of experts in the CEM area drawn from State and Local Government, researchers, industry and consultants. The indicators are a subset of the national indicators set and are those that are considered to be a high priority for monitoring in Tasmania.

Information on the national indicator set is available in the Coastal CRC Users Guide: Scheltinga *et al* (2004). Users' guide to estuarine, coastal and marine indicators for regional NRM monitoring. Report to DEH, MEWG, ICAG Revised version December 2004. Available at <http://www.coastal.crc.org.au/Publications/Indicators.html>.

The Tasmanian recommended set of indicators is described more fully in: The Tasmanian Indicator Compendium. Draft form available at <http://www.dpiw.tas.gov.au/inter.nsf/WebPages/LBUN-6N59JM?open>.

The information provided in this document draws heavily on the Waterwatch Australia National Technical Manual, especially Module 7, Estuarine Monitoring and Module 4, Physical and Chemical Parameters. It is also based on our own personal experience on the assessment of the health of estuaries and inshore rocky reefs in Tasmania (e.g. Crawford *et al* 2002, Murphy *et al* 2003, Macleod *et al* 2004, Edgar *et al* 2005, Hirst *et al* 2005).

Our main objective in developing this report is to establish a standard set of indicators and monitoring methods to be used in Tasmania. Until now, most estuaries and coastal waters in Tasmania have not been monitored in any consistent manner, if at all. Thus the value of these data is greatly reduced because it is not possible to make comparisons over time or between regions.

It must be emphasised that the monitoring methods recommended in this report are those considered to be most appropriate at the time of writing. However, they should be regularly reviewed as more data become available and modified to incorporate new and improved methods.

It is also recognised that there is a vast array of expertise and financial support amongst community groups and local councils, making the recommendation of standard monitoring methods very difficult. As a consequence we have, where appropriate, divided recommended methods into two groups: (i) simple and

inexpensive methods suited to any community group and (ii) more complicated methods requiring some expertise and often external funding.

Developing a Monitoring Program

The first step in developing a monitoring program is to identify the purpose(s) for monitoring, i.e. the objectives and the issues to be addressed. This will determine what type of monitoring program is appropriate, including which environmental variables should be monitored and the level to which they should be measured.

Monitoring may be required for a number of reasons. Examples include:

- To maintain or improve the health of an estuary by assessing changes in indicators of estuarine condition over time.
- To investigate sources and concentrations of contaminants, such as pathogens or metals.
- To assess changes in management, such as an upgraded sewage system or improved land management practices.

Additional information on developing an environmental monitoring program, such as what, where and when to monitor, specific details about each environmental variable and what information they will provide about the environment is contained in the Coastal CRC 'Users' guide to estuarine, coastal and marine indicators for regional NRM monitoring (Scheltinga *et al* 2004), Waterwatch Australia National Technical Manual and on several Australian Government websites:

- Australian Government Department of Environment and Heritage site: <http://www.deh.gov.au/water/quality/nwqms/index.html>
- Australian Government Land and Water Resources Audit/Geosciences Australia/Coastal CRC for Coastal Zone, Estuary and Waterway Management site: <http://www.ozestuaries.org/>
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality site: <http://www.deh.gov.au/water/quality/nwqms/volume1.html>

Where ever possible monitoring programs in an estuary or waterway should be coordinated between the different users of the area and existing monitoring programs. For example, monitoring by local councils, generally for recreational water quality and sewage outfalls, should be linked with monitoring of the area by community groups or industry, e.g Tasmanian Shellfish Quality Assurance Program monitoring of temperature, salinity and pathogens. By coordinating and linking monitoring, more information should be available on the condition of the estuary which is of value to everyone.

It is also important when developing a monitoring program to produce a formal plan of activities and sampling protocols, including quality assurance/quality control for the project.

Natural variability

It is most important to remember that environmental parameters vary naturally and ideally we need a measure of natural variability before we can detect and separate change caused by anthropogenic activities. For example, nitrate concentrations in coastal waters in southern Tasmania have been observed to be naturally very low over summer and much higher in winter because of the wintertime influx of oceanic waters

rich in nitrogen. These winter nitrate concentrations can also vary significantly between years, depending on the climatic patterns and oceanic currents around Tasmania. Similarly, some species of fish have major changes in abundance between years, presumably due to differing environmental conditions affecting growth and recruitment, whereas other fish species have been observed to have relatively stable population numbers between years.

Baseline/benchmark data

This represents the starting point against which changes in condition can/will be evaluated. Unfortunately little information is currently available on the condition of many estuaries and marine waters in Tasmania. A number of estuaries are already obviously degraded and no data exist on their pristine condition, making it impossible to quantify the changes that have already occurred. Thus today's condition has to be the benchmark for assessing change in the future. However, we can make comparisons between relatively undisturbed estuaries ('reference estuaries') and those that have been impacted as a means of estimating the current condition of an estuary.

As a consequence the first task in monitoring many estuaries will be to establish a comprehensive benchmark dataset of environmental condition. Future monitoring may not necessarily remeasure all variables from the benchmark dataset as monitoring programs are improved and refined, but it is very important to have a comprehensive baseline so that a variety of comparisons can be made as required in the future.

Which variables to monitor?

Water quality monitoring programs to assess the condition of rivers and coastal waters have traditionally relied on measuring water column variables such as dissolved oxygen, turbidity and nutrients in the water because they are easy to quantify and to set minimum and maximum acceptable levels. The disadvantage of water column measures, however, is that they can change rapidly, depending on the stage of the tide or particularly during flood events, and provide a simplified view of ecosystem conditions. As a consequence, many people are now advocating that more stable measures, such as invertebrate infaunal species composition and abundance should also be monitored as these measures are integrators of environmental conditions. These species are relatively immobile and there is sufficient information now available to quantify the health of an estuary based on the invertebrate infaunal community structure. The disadvantage of these indicators is that they require expertise and are relatively time-consuming, hence expensive to measure. It is also generally more difficult to quantify acceptable/unacceptable levels of change.

Because there is limited information available on the condition of most estuaries in Tasmania, a combination of water column and biological variables is recommended. This may be reduced at a later stage when more data are available and the relationship between physical/chemical and biological indicators is better known. Also, when more information is available it is likely that estuary and regional specific monitoring programs can be developed.

Where and When to Monitor

The number of sites to be monitored and how often they are monitored is likely to be a compromise between a number of strategic sites around the estuary and the funds available for analysis, people committed to monitoring and resources available (such as boats).

Where?

Ideally a minimum of 4-5 sites at key locations in an estuary or coastal waters should be monitored consistently over time. It is important that exactly the same spot is monitored using the same methods so that any changes over time are clearly identified. For some indicators, such as toxicants and pathogens, specific high risk areas may be chosen for monitoring, especially as these indicators are expensive to monitor.

The combination of tidal effects and inflow of freshwater can lead to stratification in estuaries and coastal water bodies, that is surface waters have quite different properties from deeper waters because they come from different sources. In this instance it is important to take samples at multiple depths (minimum surface and bottom) to better understand system dynamics. Point source discharges often occur at depth, and may not be fully quantified in surface samples. Ongoing review of data during the monitoring program will show the degree to which stratification impacts water quality parameters.

When?

Many water quality parameters, such as temperature, salinity, nutrients, chlorophyll-a, dissolved oxygen, turbidity, pH and pathogens can change rapidly (e.g. within minutes during and after a flash flood), seasonally due to seasonal changes in weather and hence differing rates of primary production, annually due to climate change, and over decades due to changes in land use patterns. Hence, monitoring needs to be conducted at differing time scales depending on the objective of the monitoring program.

In the past, once a month monitoring of water quality parameters has been the norm. However, the importance of measuring water quality during and after flood events is now recognised as being increasingly important to understanding how an estuary functions and the impact of land use patterns on estuarine health. For the above water quality parameters being used to monitor estuarine health, it is recommended that they are monitored seasonally, although preferably once a month, and during major flood events. The State Government is currently developing Water Quality Objectives (WQOs), which set standards for water quality for all waters in Tasmania. This process generally requires at least 24 months of data before WQOs can be determined.

Other indicators of estuarine health, such as animal and plant species abundance and habitat extent, are generally monitored less frequently, although it is extremely important to get quantitative baseline information on these variables in the first place. Also, because there is limited information available in Tasmania at present on natural

changes in animal and plant species abundance, it may be necessary to monitor more regularly (e.g. seasonally) in the first couple of years, reducing the frequency (e.g. annually or even less frequent) in subsequent years as knowledge of the ecosystem is refined and developed. Habitat extent, measured by habitat mapping, generally will be necessary approximately every 5 years, except for mapping seagrass beds, which should be conducted more regularly and preferably every year in selected areas.

Mass mortalities, algal blooms, and community monitoring of invasive species should be monitored when these events occur. Indicators that are expensive to monitor, such as toxicants, are generally only monitored when there is cause for concern of contamination occurring in the estuary or coastal waters. Some existing monitoring programs may already incorporate parameters such as toxicants in estuarine and coastal waters (e.g. Tasmanian Shellfish Quality Assurance Program) so economies may be gained by linking with existing monitoring programs.

Normal vs. special event conditions

As mentioned above, some environmental variables, especially water quality measures, can change dramatically between normal conditions and during floods. For example, the first flush of flood waters into an estuary after a period of drought is likely to contain significantly higher levels of nutrients, suspended particles, heavy metals and pathogens that have been washed off the land during heavy rainfall. Currently the importance of these flood waters to estuarine health is under debate and we need to obtain more data on the environmental condition of estuaries during and after floods to be able to assess the importance of these events. This is particularly important in determining the requirements of estuaries for environmental flows. Thus we recommend event based sampling of water quality parameters where possible. In many cases sampling in estuarine waters during flood events is too dangerous and the best place to take samples would be from a bridge located either on or just above the estuary.

Associated with measuring water quality parameters during normal and flood events, is the importance of having measurements of water flow. This enables calculations of loads into estuaries of, for example, nutrients or sediments, rather than just concentrations at the time of measurement. A number of rivers in Tasmania have gauges on them for measuring flow rates and this information is available from the Water Information System of Tasmania website managed by DPIW, at <http://water.dpiwe.tas.gov.au/wist/>. Flow information should be included in monitoring reports.

Timing of monitoring

Unlike in freshwater, some estuarine environmental variables vary significantly according to the stage of the tide. It is therefore important to monitor at the same stage of the tide each time. A commonly accepted practise is to monitor water column variables during the outgoing tide and preferably as close to slack low tide as possible. Any nutrients or contaminants entering an estuary in inflowing freshwater are likely to be most concentrated at low tide and hence more readily detected. However, to better understand how estuaries are functioning, it is important to have

some data collected over a full tidal cycle. This should be a component of the baseline assessment and should be repeated occasionally during ongoing monitoring.

Safety during monitoring

Safe monitoring methods are of utmost importance as the estuarine and inshore water environments are renowned for their unpredictability and rapidly changing conditions. Rogue waves, rapidly changing tides, changes in sea condition from calm to crashing waves, partially submerged floating objects and sudden changes in water depth are not uncommon in estuaries. Thus it is essential that monitoring in estuaries is never conducted alone and a constant eye is kept on the weather and surrounding conditions. Personal floatation devices must also be worn at all times when sampling from a boat or in streams.

Data Storage

How and where to store data is currently being assessed by a subgroup of the CEM Indicators Working Group and by NRM regional and state-wide staff. A possible location for storing water quality data is in the Hydstra database which is maintained by DPIW for their freshwater monitoring data. It now also stores most of the Waterwatch data from Northern Tasmania. The information is then accessed using specially designed software such as 'Splashback'. DPIW maintains a marine pest database for Tasmania and it is possible that this could incorporate pest data from monitoring programs. For community collected data such as mass mortalities and litter, appropriate data storage locations may be with local councils.

However, a number of issues relating to data storage are still to be sorted out, including who will maintain the databases, access conditions, intellectual property and ranking of quality standards. Details of the structure and format that the data are required in are also to be determined.

Until this is resolved, it is important to store data in Excel or Access database files and to copy the results to CD as a backup.

Data Evaluation and Reporting

Regular evaluation of the data collected is an essential component of any monitoring program, but unfortunately this aspect is often overlooked. It is very important to ascertain at the beginning of a monitoring program who will assess the data while the monitoring program is underway and factor this into overall program costs. This ongoing assessment is necessary to identify sudden changes in results, which may be due to a sudden impact occurring or equipment not operating properly etc.

It is also essential to determine at the beginning who will analyse, evaluate and report on the data on a regular basis, such as annually, and to allocate funding for this. This should be conducted by someone with expertise in the ecology of estuarine and coastal waters and training in data analysis and assessment. This evaluation should also periodically include an assessment of the suitability of variables being

monitored, the sites being sampled and times of sampling. Over time as more data become available, it should be possible to refine the monitoring program.

Annual assessments in the form of an Annual Report Card are currently being developed for some Tasmanian estuaries and coastal waters. These report cards provide a summary of the condition of waterways over the previous twelve months, based on the data that have been collected during this period, for example the Derwent Estuary Program Annual Report Card. In some cases the report cards contain a ranking of the condition of estuaries from excellent to very poor. The NRM regions are very keen to establish this report card system for estuaries and coastal waters in their areas.

As mentioned above, separating natural changes from human-induced ones can be very difficult. There is a large amount of scientific information available on the experimental design and statistical analyses required to monitor estuaries and provide scientifically accurate and reliable estimates of change. Where possible this scientific methodology should be adhered to. However, in some cases the resources may not be available to adequately monitor estuaries to enable statistical analysis. The number of sites and frequency of sampling is related to the natural variability in a parameter; the greater the natural variation the more sampling that is required to determine human-induced change above natural variation. When the sampling is not sufficient for robust analysis the monitoring programs can only suggest that change is occurring and trigger the need for more detailed evaluation.

Indicators

Table 1. Summary of recommended indicators of the condition of estuaries and coastal waters in Tasmania and whether they are suitable for community or expertise-based monitoring.

<i>Basic measures of ecosystem condition</i>	<i>Community-based monitoring</i>	<i>Expertise-based monitoring</i>
Temperature	√	√
Salinity	√	√
Dissolved oxygen (especially bottom waters)	√	√
Turbidity	√	√
Chlorophyll-a	?	√
Habitat extent	?	√
<i>Important indicators</i>		
Animal and plant species abundance		√
Shoreline position	√	√
Nutrients in the water column	?	√
Toxicants		√
Pathogens	?	√
pH	√	√
<i>Community monitoring</i>		
Algal blooms	√	√
Mass mortalities	√	
Litter	√	
Invasive species	√	√

Basic site information

For each estuary/coastal waters being monitored it is important to have a map of the region and to locate sampling sites along the estuary/coastal waters in areas with easy access. At each sampling site it is essential to document background information on each monitoring occasion, including:

- the name of the person conducting the monitoring
- the date and time of day
- state of the tide
- weather conditions
- any notable observations

Physical-Chemical Indicators

Temperature and salinity are recommended for monitoring, largely to supply supporting information, rather than as indicators themselves of CEM condition. Both temperature and salinity affect many physical, chemical and biological characteristics and processes with an estuary or coastal waters. As they both affect dissolved oxygen concentration, temperature and salinity must be recorded in conjunction with measurements of this parameter.

Temperature

Water temperature is a key factor controlling the rate of biological processes. An increase or decrease in temperature can have substantial effects on the physiology of the biota and aquatic ecosystems functioning.

Temperature increases can be caused by heated effluent and decreases from the release of cold water from water storages. Temperature recorded over long periods of time (years) is an indicator for global warming.

Water temperature can be measured using a thermometer or a field meter with temperature probe. Low risk trigger values for temperature for the protection of aquatic ecosystems can be defined by the 20thile and 80thile of the seasonal distribution for the reference sites. Temperature change of more than 2 C at the test sites from reference sites should be investigated.

Salinity (Electrical conductivity)

Salinity is a measure of the amount of salt in water. It is an indicator used to understand the hydrodynamics and mixing processes occurring in an estuary as freshwater mixes with seawater. Salinity is also an important factor in the ecology of an estuary as many organisms can only survive within a limited salinity range. It is a key indicator affected by environmental flows into estuaries.

Seawater is measured by marine biologists as parts per thousand or PSU (Practical Salinity Units). Full seawater has a salinity of approximately 35 parts per thousand (ppt). However, most people working on freshwater systems measure salinity as electrical conductivity in microSiemens/cm. Full seawater is typically 51,500 μ S/cm.

Salinity is generally measured using a field meter, although it can also be measured using a refractometer or a hydrometer which records specific gravity. The advantage of a field meter is that the salinity probe is attached by a cable to the meter and thus can be used to profile salinity values from the surface to adjacent to the seabed. Because freshwater is less dense than seawater it generally flows over the top of saline waters and in this situation salinity increases with water depth and the estuary is considered to be stratified. The penetration of the underlying salt wedge up an estuary can be an important factor in determining the functioning of an estuarine system. If these underlying waters become isolated from oxygenation processes such as surface water exchange or photosynthesis they can become very low in dissolved oxygen (hypoxic) and hence harmful to many organisms. However, many shallow

estuaries are well mixed by tidal currents and wind resulting in uniform salinity through the water column, but decreasing with distance up the estuary.

Low-risk trigger concentrations for salinity (or EC) for the protection of the aquatic ecosystem can be defined as the 20thile or 80thile of the reference system(s) distribution, depending upon whether low salinity or high salinity effects are being considered. Establishment of salinity profiles over a range of tidal and flood conditions can help with the design of a field program.

Turbidity

Turbidity is a measure of the amount of suspended material in the water column, or cloudiness. Increased turbidity reduces the penetration of light in water and affects the depth at which submerged aquatic vegetation can grow. High turbidity levels may indicate erosion, sediment resuspension, wastewater discharge or algal blooms.

Because increased turbidity commonly occurs as a result of altered land-based activities, such as land clearing, intensive agriculture, and urban development, it is an important indicator of CEM condition.

Turbidity is commonly measured using a portable turbidity meter or a turbidity probe and the units of measurement are NTUs (Nephelometric Turbidity Units). A secchi disc, which is simpler and cheaper, is also often used as a surrogate measure of turbidity. This disc is slowly lowered through the water column, and the depth at which the disc disappears from sight is recorded. As such it is measuring light attenuation rather than turbidity and hence is only suitable in areas with normally “clear” water. It is not suitable in areas with naturally dark coloured tannin in the water. Secchi discs can also only be used in water deep enough so that the disc disappears from view before it hits the bottom.

Low-risk trigger concentrations for turbidity (or suspended solids) for the protection of aquatic ecosystems should be determined as the 80%ile of the reference system(s) distribution.

Dissolved oxygen

The concentration of dissolved oxygen (DO) is an important measure of the health of an estuary. Decreases in DO are often related to increased organic load, such as from sewage, algal blooms and influx of organic matter into an estuary. This increase in organic load can lead to increased bacterial activity, resulting in greater oxygen consumption. As a consequence, the available oxygen, especially in bottom waters, can become depleted. *It is thus important to measure dissolved oxygen in bottom waters.* Dissolved oxygen can also vary significantly over 24 hours, and this should be factored into data interpretation.

Dissolved oxygen is commonly measured using a field DO meter and probe. These probes are sensitive and need to be carefully handled and maintained. Some field meters automatically correct for temperature and salinity; if not then this calibration

will need to be done manually. Results can be reported as either mg/L or percentage saturation.

It is our experience that dissolved oxygen meters used in estuaries are temperamental and need regular servicing (approximately every 6 months). We also recommend periodic checks of DO probe readings with the more accurate Winkler titration method. Calibration of the instrument should be conducted on each monitoring occasion.

Note: dissolved oxygen concentrations decrease with increased temperature and salinity. Thus temperature and salinity need to be measured at the same time as DO.

Low risk trigger values for DO for the protection of aquatic ecosystems can be defined by the 20thile and the 80thile of the seasonal distribution for the reference sites.

pH

pH measures acidity or alkalinity of water on a log scale from 0 (extremely acidic) to 14 (extremely alkaline). A pH of 7 is neutral and most CEM organisms prefer a pH in the range of 7-8.5. pH is generally relatively stable in estuarine and marine waters because of carbonate buffering. However, significant changes in pH may occur due to disturbance of acid sulphate soils from mine drainage or chemical pollution.

An altered pH that is higher or lower than that normally encountered by marine organisms can result in tissue damage, leading to death. Changes in pH can also affect the availability of metals and the solubility of calcium carbonate, which is important for shell-forming organisms. pH changes of more than 0.5 pH units from the seasonal maxima or minima defined by the reference sites should be investigated. Low risk trigger values for pH for the protection of aquatic ecosystems can be defined by the 20thile and the 80thile of the seasonal distribution for the reference sites.

pH has not been commonly measured in Tasmanian estuarine and coastal waters, and although recommended, is not considered as essential as the other physical-chemical parameters, except in areas with potential acid-sulphate soils. If monitoring in relation to acid-sulphate soils it is important to measure pH immediately after rainfall events, especially the first run-off of water from likely affected acid-sulphate areas. If there is evidence of urban or industrial impacts, pH can be used successfully as a tracer of plumes or point sources.

pH of water is generally measured in situ using a field meter with a pH probe. These field probes are generally robust and reliable provided they are well maintained and calibrated. Liquid test kits or test strips for community measuring of pH are also available.

Automatic monitoring of physical-chemical parameters

Continuous monitoring of physical/chemical properties of water is becoming more commonplace as technology develops and prices decrease. Nevertheless, experience in Tasmania has shown that this is not as simple as it appears, especially when trying

to telemeter results to computers on land to provide results instantaneously. Temperature is by far the easiest and cheapest to record continuously by placing a temperature probe on the seabed and retrieving it months/years later and downloading the data. Salinity probes are the next simplest, although they, like other probes, are prone to fouling and thus loss of accuracy.

All probes continuously in the water need checking and removal of fouling organisms approximately every two weeks. Chlorophyll-a probes (measuring fluorescence) are available, but are prone to clogging and need regular maintenance. Our experience of continuously monitoring dissolved oxygen probes in estuarine waters is that they are unreliable and are generally not recommended at this stage (in contrast to dissolved oxygen probes in freshwater which generally work well). A new generation of dissolved oxygen sensors are now available, which may prove to be more reliable for remote or automatic applications.

After some years of development, there are several continuously operating systems in Tasmania. Lessons to be learnt include finding a suitable location for the monitoring system and location of receivers. It is also very important to have backup technical support for both the set up and maintenance of the systems in the field and for trouble shooting problems with either the hardware or the associated software. Several automatic monitors in estuaries are now working well, largely because commercial off-the-shelf equipment that had backup technical support was purchased. The software is also becoming much more user friendly.

Note that when purchasing automatic monitoring equipment, there are 'hidden' costs that are essential to the operation of the equipment. The data logger alone is relatively cheap; for example temperature data logger (\$170), but the costs of essential software (\$150) and optical downloader (\$150) rapidly increase the price of the equipment (although a once only cost and can be used for multiple temperature loggers). We have also found for multiprobe systems that it has been necessary to employ an experienced technician to install the equipment and get it operational.

Nutrients in the water column

Nutrients in the water column include both organic and inorganic forms, and can be either dissolved or particulate. Dissolved inorganic nutrients are the most biologically available and thus in excess are likely to impact on estuarine and marine systems, particularly through excessive plant growth leading to eutrophication.

Nitrogen and phosphorous are essential building blocks of animal and plant life and are cycled through the environment by biological and chemical means. In the marine environment nitrogen is often the limiting nutrient for growth, whereas in freshwater it is mainly phosphorous.

If funding is limited it is recommended that biologically available dissolved nutrients (nitrate + nitrite, phosphate and ammonium) are monitored as a priority. However, if sufficient funding is available and information is required on nutrient loads from rivers into estuaries, total nitrogen (TN) and total phosphorous (TP) should also be monitored.

Water samples for ammonium analysis are easily contaminated and great care must be taken in collecting these samples. For example, they can not be collected by a smoker because nitrogenous tar on fingers can contaminate samples. Similarly, water samples need to be collected away from the exhaust of outboard motors.

Note: because nutrient concentrations can be very low in Tasmanian waters, field measurements using a colour comparator or colorimeter are not appropriate as they cannot measure low nutrient levels. Water samples need to be sent to an accredited laboratory for analysis. In Tasmania this is the State Government Laboratories (Analytical Services Tasmania, AST) at Sandy Bay in Hobart. The laboratories provide sample bottles, filters as required, information on how to collect and process the water samples in the field, and guidance on how long samples can be stored before analysis. Water samples for nutrients are either delivered fresh to the laboratory on the day of sampling or refrigerated at 4° C (filtered samples can be frozen), and delivered later. However, silicate samples can not be frozen.

Quotation for analysis provided by AST in May 2006 (including GST)

\$35.10 Nutrients, Dissolved (ammonia, nitrate+nitrite, phosphorous dissolved)
\$29.55 Nutrients Total (total nitrogen, total phosphorous)
\$23.76 Project administration charge (charged once only per batch of samples submitted, i.e. the same cost whether 1 or 100 samples)

This quote is for 1 water sample, but discounts apply for larger numbers of samples.

Contact details:

Analytical Services Tasmania
C/- Chemistry Dept., University of Tasmania
Sandy bay, Tasmania 7005
Ph 6226 7175; Fax 6226 7825
Email: astproduction@environment.tas.gov.au

We are also investigating the costs of getting analyses conducted in other states.

Chlorophyll-a

Chlorophyll-a (Chl-a) is the green photosynthetic matter found in plants and thus is a measure of the biomass of plant material, mainly microscopic algae (phytoplankton) in the water column. High concentrations of Chlorophyll-a indicate algal blooms and possible eutrophication of an estuary with reduced dissolved oxygen concentration and water clarity. Identification of the species involved is generally recommended if the Chl-a values are high to determine whether any of the species are toxic to other aquatic organisms and as a general indication of the likely impact on the estuary.

Chl-a is measured by taking water samples in the field and sending them to a laboratory for analysis using a spectrophotometer. These samples are collected either as discrete sample, (usually taken at the surface) or as a depth integrated sample using a Lund tube or descending pump. Submersible field data loggers can also be equipped with chlorophyll a sensors. These loggers are usually cost prohibitive, but provide a real-time profile of chlorophyll a distribution that can assist with where in the water column to collect a water sample from.

The laboratories provide a 1 L plastic bottle for the water sample. After the sample is taken it should be kept cool (on ice), wrapped in aluminium foil and transported to the lab as quickly as possible.

Quotation for analysis provided by AST in May 2006 (including GST)

- \$59.50 Chlorophyll-a in water, including filtration and extraction
- \$23.76 Project administration charge (charged once only per batch of samples submitted, i.e. the same cost whether 1 or 100 samples)

The costs of analysis can be considerably reduced if the water sample is filtered and the concentrated algae frozen in the field.

- \$11.71 Chlorophyll-a on a filter

The Waterwatch Australia National Technical Manual Module 7, Estuarine Monitoring, (2006) provides a detailed description of how to filter the water sample in the field and submit the concentrated chlorophyll-a sample on filter paper to a laboratory for analysis. Note that it is important to keep the vacuum pressure at -20 kpa; if the pressure is too high the algal cells will be broken and sucked through the filter paper. This procedure does, however, require some scientific knowledge and training. The main advantage of filtering the sample is to reduce the costs of analysis. However, Analytical Services Tasmania cannot provide a result meeting their guaranteed laboratory standards as they have not filtered the sample.

CSIRO phytoplankton experts have suggested that algal bloom conditions can be considered to exist when the Chl-a concentration is three times above the median value (Volkman *et al* 2005). Further data are being collected to test this hypothesis.

Algal blooms

Chlorophyll-a is the agreed first priority quantitative measure of algal biomass as it is widely used and the results are easily interpreted. However, because algal blooms are generally infrequent and unpredictable, information collected by on-the-spot community groups can be extremely valuable.

Algal blooms take two forms:

- (i) *Microalgae (phytoplankton) in the water column.* Microalgae are too small to be individually seen by the naked eye, and these blooms are observed as regions of coloured water; for example green/brown water that can occur in estuaries especially after sewage spills or the obvious fluorescent pink blooms of *Noctiluca scintillans*.
- (ii) *Macroalgae in shallow water and the intertidal zone.* Some species of macroalgae proliferate in areas of high nutrients, leading to dense algal mats that can be detrimental to estuarine function by blocking light, and severely reducing dissolved oxygen concentrations. Several groups of macroalgae found in Tasmania also occur worldwide and are universally known as 'nuisance algae'. These include the sea lettuce (*Ulva* sp.), the

green slimy algae (*Enteromorpha* sp.) and filamentous algae attached to other plants or the seabed, such as *Chaetomorpha* sp.

Note: both micro- and macro-algal blooms can occur naturally and are not necessarily an indication of human impact or degradation. For example, influxes of nutrient rich southern ocean waters during winter in southern Tasmania have been observed to result in dense macroalgal mats in areas with minimal human activity. Some phytoplankton blooms occur with species that produce toxins, which can irritate skin or cause respiratory distress. Take appropriate precautions when handling algal bloom samples.

Expertise-based monitoring

Microalgae- Generally a water sample is collected using an integrated sampler (plastic tubing of 10 m depth or shorter in shallower areas) or at specific depths using a Niskin bottle or a phytoplankton net. 1 litre of this water is collected in a plastic jar and preserved with 4 ml of Lugol's iodine. In the laboratory the algal species are identified and the number of cells counted to determine the density of each species.

A quote from Analytical Services Tasmania in June 2006 (including GST)

\$83.27 Algal Counts in Water by Optical Microscopy per sample

\$53.57 Algal Identification per sample

\$23.70 Project administration (charged once only per batch of samples submitted, i.e. the same cost whether 1 or 100 samples)

Macroalgae- Intertidal and shallow water monitoring of macroalgal blooms, generally on gently sloping sand/mud flats, but can also include rocky shores, involves dividing the area to be monitored into 10 m x 10 m squares using a grid on an aerial photograph and randomly selecting approximately ten of these squares to be examined. Within each of these squares ten stations are randomly selected using a grid. The percentage cover of algal species in a 0.5 x 0.5 m quadrat placed in the centre of each station is estimated. The position of each 10 x 10 m square and station is recorded using GPS.

The number and size of squares to be monitored will vary depending on the location. For example, on rocky shores with steep slope and in much of Tasmania where the tidal range is only 1 m, the intertidal zone is very narrow. At these sites the 'squares' will need to be longer and narrower and a greater number of 'squares' allocated around the shoreline. They should be located in the mid to low intertidal zone of an average low tide. Macroalgal monitoring is preferably conducted seasonally as different species of algae are most abundant at different times of year. If conducted annually it is important that the monitoring is conducted at the same time each year.

Community-based monitoring

Microalgae and macroalgae- This is primarily a visual assessment, including photographs or video footage and details of the location, extent (area) of the bloom and environmental conditions at the time. This may include taking samples for expert identification of the species involved. Some community groups may wish to monitor macroalgal blooms as described above.

Other information

Short courses (2-3 days) on the microscopic identification of phytoplankton commonly found in Tasmanian waters are periodically held by the School of Plant Science at the University of Tasmania; contact Prof. Gustaaf Hallegraeff. Ph. 62262623

Descriptions of the common species of macroalgae are available in texts such as Edgar *et al* (1997); however many macroalgae found in Tasmania are difficult to identify and not all species have been described.

There is no agreed definition of what constitutes a microalgal bloom from either measurement of Chl-a or cell counts. This makes accurate recording of algal blooms difficult and further work is required in Tasmania. As noted in the Chlorophyll-a section, CSIRO phytoplankton experts have suggested that an algal bloom occurs when the Chl-a concentration is three times above the median value (Volkman *et al* 2005). Further data are being collected to test this hypothesis.

Extent/distribution of key habitat types

The health of estuaries and coastal waters depends on the maintenance of a diverse range of habitats. Loss of habitat results in the loss of organisms that need that habitat to survive and thus a decrease in biodiversity. It can also result in loss of recreational value and commercial use, tourism and conservation values. Habitat loss is caused by a variety of human activities including construction of marine facilities, roads, jetties etc, reclamation, urbanisation, dredging, trawling, aquaculture, tourism and unregulated recreational activities.

Intertidal to 100 m inland from mean high water

Expertise – Regional mapping of intertidal and foreshore habitats, including saltmarshes, requires some expertise and experience. Generally data are collected using ortho-rectified aerial photographs and high definition satellite imagery and ground-truthed, with the data being presented in GIS digital layers.

Community – Mapping the distribution of key foreshore and intertidal habitats in a localised area can generally be undertaken by community groups using aerial photography and groundtruthing the habitat types identified. Some aspects of habitat mapping will require expert advice, such as interpretation of satellite images or plant species identification.

A project currently underway in the Southern NRM region is mapping selected intertidal and foreshore habitat to determine baseline condition and pressures impinging on each habitat. This project will establish reference sites for key foreshore habitats in the region and will recommend monitoring procedures.

TASVEG, the Tasmanian Vegetation Map produced by the Tasmanian Vegetation Mapping Program of DPIW has mapped and described 158 mapping units in Tasmania, most of them ecological vegetation communities including saltmarshes and coastal vegetation (described in Harris and Kitchener 2005). This information is valuable to the mapping of coastal habitats.

Subtidal - expertise-based

Mapping of underwater habitats is more complex, especially as aerial photographs are rarely taken under the right conditions to be able to identify seabed habitats. The Tasmanian Aquaculture and Fisheries Institute (TAFI) have developed the SEAMAP Tasmania Program to map coastal waters to 40 m depth, and are progressively mapping estuaries and inshore waters around Tasmania.

Habitats mapped by SEAMAP Tasmania include different sediment types of sand, mud, reef, gravel and seagrass and macroalgal beds. The habitat classification system developed by TAFI is recommended for habitat mapping in Tasmania to ensure consistency of reporting. The method used by TAFI includes aerial photography (including purpose flown aerial surveys if necessary), satellite imagery and acoustic surveys using a single beam echo sounder or sidescan sonar, and ground-truthing

using video photography. Locations are accurately recorded using digital GPS. SEAMAP involves relatively complex mapping procedures and software which have been developed over several years by research scientists and are regularly being improved. It is able to provide estimates of the accuracy of mapping which is important for assessing any change in the future.

Details of the TAFI SEAMAP Tasmania project and the habitat maps prepared by TAFI are available at <http://thelist.tas.gov.au/asdd/ANZTA0025000006.html>.

Animal or Plant Species Abundance

Animal or plant species abundances are important measures of estuarine health and water quality. This is because physical and chemical measures of water quality can vary rapidly (within 24 hours) by an order of magnitude or more due to changing environmental conditions, such as flooding into an estuary. By contrast, animal and plant species abundance generally do not change so rapidly and are therefore a better integrator of environmental conditions over time.

Obviously not all plant and animal communities can be monitored. In Tasmania rocky reef habitats have been identified by government and NRM committees as a high priority marine habitat because they contain the two main commercial species, rock lobster and abalone, and they are important for recreational fishing and diving. In estuaries, the dominant habitat type is soft sediment and assessment of estuarine invertebrate fauna living in sand and mud sediments has been identified by government experts and researchers as a good indicator of water quality and estuarine health. These infauna do not regularly move around and are not readily dislodged (compared with fish or surface dwelling invertebrates).

Animal and plant species abundance on subtidal rocky reefs

Expertise-based monitoring

A standardised method for expertise-based monitoring of inshore rocky reefs has been developed by the Tasmanian Aquaculture and Fisheries Institute. This methodology has been used to assess the condition of approximately 180 coastal reefs around Tasmania, and for changes in Marine Protected Areas in Tasmania and other southern Australian States, e.g. Edgar and Barrett (1999), Barrett and Buxton (2002).

At each site the abundance and size structure of large fishes, the abundance of cryptic fishes and benthic invertebrates, and the percent cover of macroalgae, corals and other cover-forming invertebrates, are each censused separately along four 50 m long transects. Transect lines are laid end to end along a fixed depth contour (generally 5 m or 10 m depth) and the position of each is recorded using a GPS based on the WGS84 Datum System.

For fish transects, the density and estimated size-class of fish within 5 m of each side of the line are recorded on waterproof paper, with the diver swimming up the offshore side of the line and then back along the inshore side in the middle of a 5 m wide lane. Size-classes of total fish length used are 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 375, 400, 500, 625, 750, 875 and 1000+ mm. Lengths of fish >1 m length are individually estimated.

Cryptic fishes and megafaunal invertebrates (large molluscs, echinoderms and crustaceans) are counted and certain fisheries species measured (abalone and rock lobster) along the transect lines used for the fish survey by recording animals within 1 m of one side of the line (a total of four 1 m x 50 m transects).

The area covered by different macroalgal, coral, sponge and other attached invertebrate species are quantified by placing a 0.25 m² quadrat at 10 m intervals along the transect line and assessing the percent cover of the various plant species (a total of 1.25 m² for each of the 50 m sections of transect line).

For more details see Barrett and Buxton (2002), TAFI Technical report # 11, available at:

http://www.utas.edu.au/tafi/TAFI_Download.htm#TAFI%20Technical%20Reports

Community monitoring:

Monitoring of subtidal habitats is generally not suitable for community-based monitoring because of the safety issues associated with diving, the requirement for boats and the importance of having a detailed knowledge of subtidal flora and fauna. An assessment of volunteers from diving groups in Southern Tasmania concluded that community based monitoring may provide data of sufficient reliability to be able to detect change in reef ecosystems over time provided that good training and professional facilitation of volunteers was available. However, unless this is organised by volunteer organisations on a large scale, the data are likely to be collected more cost-effectively and reliably by trained researchers (Barrett *et al* 2002).

Animal species abundance in soft sediments:

Expertise-based monitoring

Standard methodology has been developed by TAFI for the assessment of estuarine invertebrate fauna, which has been used in numerous studies on the impacts of salmon and shellfish farms on the environment and the condition and conservation status of Tasmanian estuaries (e.g. Edgar *et al* 1999, Crawford *et al* 2003, Macleod *et al* 2004, Hirst *et al* 2005).

Sediment samples for assessment of invertebrate infauna are collected in shallow water using a hand held 150 mm diameter PVC pipe corer (sediment depth 100 mm; sample area 0.0177 m²) (Fig. 1b). In deeper water sediment samples are collected either by diver using the PVC pipe corer or from a boat using a Van Veen Grab (sampling area 0.05 – 0.1 m²).

A minimum of three replicate grabs/cores is recommended be collected at each station.

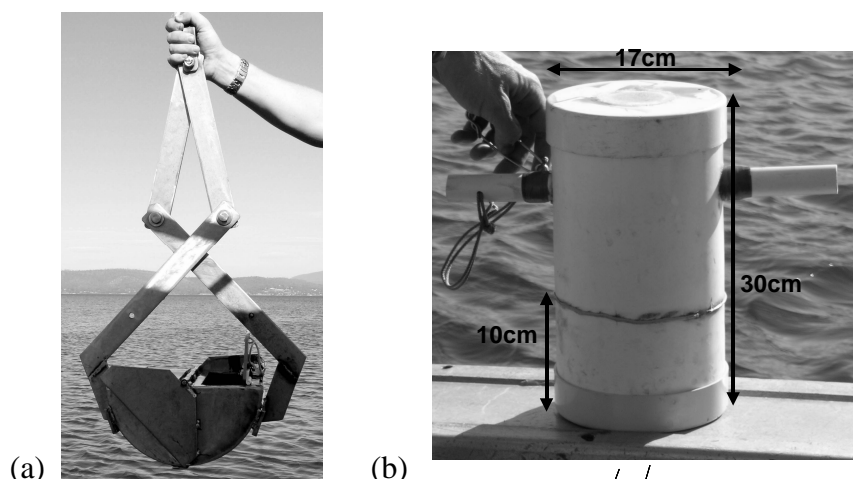


Figure 1. a) Van Veen grab in closed position, b) PVC pipe corer showing dimensions.

The grab/diver sample is washed through a 1 mm mesh sieve and the material retained placed in storage containers and completely covered with 10% formalin buffered in seawater for a minimum of 48 hours to ensure complete fixation. It can then be stored in 70% alcohol.

In the laboratory the organisms are separated from the sediment and the species present identified to the lowest possible taxonomic level and each taxa counted.

Salmon farm assessments have identified several key species/communities that are indicative of the levels of organic enrichment:

Unimpacted conditions

- Brittle stars /other sensitive species e.g. crustaceans *Ampelisca* sp./*Apseudes* sp.
- Number of species comparable with reference conditions.

Moderate Impact

- Number of species may be reduced (>50% of reference)

High organic enrichment

- Samples dominated by capitellid polychaetes / abundant opportunistic species, e.g. *Nebalia longicornis*, *Ophryotrocha*
- Considerable reduction in species diversity (<50% of reference)

Identification of invertebrate species to family level has been shown in a number of studies (Somerfield *et al* 1995, Vanderklift *et al* 1996, Olsgard *et al* 1998) to be sufficient to identify substantial change in environmental condition. It is much quicker and hence cheaper to monitor to family level than to species. In addition, stable communities may be characterised by particular species/taxa which are identified as part of an expert baseline survey and form the focus on ongoing community monitoring. However, if the objective is to assess biodiversity, then identification to species levels is essential.

Community-based monitoring

A simplified method of sampling invertebrate fauna in the sediments around fish farms, which is suitable for trained farm hands to use, has been developed by TAFI.

This is documented in the 'Guide to the assessment of sediment condition at marine finfish farms in Tasmania' by Macleod and Forbes, (2004), available at http://www.utas.edu.au/tafi/TAFI_Download.htm#TAFI%20Technical%20Reports, TAFI Reports to Funding/Other Bodies. It is highly probable that this methodology could be adapted for community groups.

Seagrass monitoring

Expertise-based monitoring

Expertise-based monitoring of the abundance/extent of seagrass beds is described in the section on Extent/distribution of key habitat types. Because many seagrass beds in Tasmania are subtidal, mapping their extent is relatively complex and generally not suited to community groups. However, in small estuaries community groups would be able to map the boundary of beds using a GPS and snorkelling or from a boat.

The condition of seagrass beds is measured using percentage cover, density, epiphyte (filamentous algal) and macroalgal cover. Representative sites in the seagrass bed are selected and a 50 m transect line laid out across the bed, generally perpendicular to the shore. A 50 x 50 cm quadrat is laid next to the quadrat at 10 cm intervals along the transect and the percentage cover of seagrass in the quadrat is recorded. The species of seagrass and the percentage cover of each species are also noted. The percentage of seagrass leaf area covered by epiphytes is measured and the percentage cover of both filamentous and macroalgae on seagrass in the quadrat is estimated. This procedure is repeated twice (3 transects at each site) and the position of each transect is recorded using GPS.

Community-based monitoring

Community-based monitoring of seagrass beds is relatively common in mainland Australia, for example Seagrass Watch in Queensland. This has not occurred in Tasmania, presumably because of the colder water, low tidal range around much of the coastline and limited distribution of extensive seagrass beds near the higher populated areas.

The methods generally used for monitoring seagrass condition are similar to those described above for expertise-based monitoring. A useful manual for community monitoring of seagrass is the Parks Victoria Technical Series No. 16, *Sea Search: Community-based monitoring of Victoria's marine national parks and marine sanctuaries – Seagrass monitoring* by Koss *et al* (2005) available at http://www.parkweb.vic.gov.au/resources/19_1326.pdf. This report describes seagrass species commonly found in Tasmania. However, the methods used to monitor seagrass condition are slightly different to those that have been employed in Tasmania.

Seagrass condition naturally changes between seasons and thus seasonal monitoring is necessary if these natural trends are to be identified. Annual monitoring in Tasmania, however, may be preferred to avoid the cold winter conditions. For annual monitoring it is important to monitor at the same time each year to avoid the seasonal changes.

Although sea grass communities are susceptible to changes in water quality and thus are widely considered to be an important indicator of environmental health, differences between species in their ecology and reproduction need to be taken into consideration when assessing abundance data. For example, *Heterozostera tasmanica*, which is widely available in shallow habitats around Tasmania, has been observed to have substantial natural fluctuations in abundance. *Posidonia australis*, however, which occurs on the northern coastline has very stable beds, which if disturbed take many years to recover, if at all.

Intertidal monitoring of macroalgae is described in the Section on Algal Blooms. Monitoring of intertidal fauna is considered to be a relatively low priority because of the lack of baseline information around Tasmania.

A recommended general book for identification of estuarine and marine flora and fauna is *Australian Marine Life, the plants and animals of temperate waters* by Edgar (1997). As the author is Tasmanian, this book contains many photographs of animals and plant found in Tasmanian waters.

Invasive species

Invasive plants and animals are those that do not naturally occur in an area or those that have increased in number to the extent that they are altering the natural ecosystem. Most invasive species have been introduced by human activity, such as shipping (e.g. hull or ballast water fouling) or escaped aquarium species. Invasive species have the potential to cause major damage to estuarine and coastal waters by altering the natural biodiversity and affecting aquaculture production and wild harvest. They may also impact on humans through reduced recreational amenity and producing seafood that is unsafe for human consumption.

There are 58 introduced marine species that have been identified in Tasmania, 10 of which are recognised as marine pests. The Department of Primary Industry and Water (DPIW) maintains a database of invasive marine species found in Tasmania. This includes the Pacific seastar, *Asterias amurensis*, New Zealand screw shell, *Maoricoprus roseus* and the Japanese seaweed, *Undaria pinnatifida*, as well as the less obvious but regionally abundant introduced species such as the small bivalves, *Cobula gibba*, *Theora lubrica*, *Raeta pulchella* and the European/green shore crab, *Carcinus maenas*.

The Australian Government has recognised the threat posed by invasive species and has developed a National System for the Prevention and Management of Marine Pest Incursions. The Tasmanian Government has signed an inter-governmental agreement to participate in this national system and has agreed to monitor high priority areas within its jurisdiction. A National Introduced Marine Pest Coordination Group (NIMPCG) has been formed to develop the implementation of the national system.

Because the main source of invasive species is through shipping activities, baseline surveys of invasive species have been recently conducted in all the main ports in Tasmania. NIMPCG is currently producing a monitoring strategy, including a decision support system and a manual of monitoring protocols for invasive species,

which will be available by end of 2006. Priority areas are being targeted and the Port of Hobart will be monitored by the Tasmanian Government. Other ports are likely to be monitored, possibly in partnership between State Government, local Port Authorities and Regional NRM groups, although these discussions are yet to take place.

The monitoring manual will describe monitoring protocols including annual and targeted species-specific monitoring. Ports participating in this national system must monitor invasive species according to the protocols described in the manual. This requires a relatively high level of monitoring expertise and experience in identification of floral and faunal species.

Community-based monitoring of invasive species is likely to be conducted as part of monitoring other indicators and to generally add to the existing database of location and abundance of invasive species. Identification of and information on invasive marine species in Australia can be obtained from the CSIRO publication 'A guide to the Introduced Marine Species in Australian Waters' by Diane Furlani (1996). CSIRO have also produced a series of fact sheets on marine pests, available at http://crimp.marine.csiro.au//Marine_pest_infosheets.html

Experts at the Queen Victoria Museum in Launceston and the Tasmanian Museum and Art Gallery in Hobart can assist with the identification of invasive marine species. Any new discoveries of invasive species or extensions in distribution beyond the known range should be reported to DPIW.

Mass Mortalities

This indicator is primarily for community monitoring because it relies on reports of sporadic mass mortality events that would not normally be picked up in a routine monitoring program. Such information can be extremely useful in identifying a pollutant source or cause of harm to marine and estuarine flora and fauna.

Fish or invertebrate kills (e.g. crabs) are unexpected and generally short lived. The frequency and magnitude of such events is an indicator of the health of an estuary. Causes include low dissolved oxygen levels, disease, toxic algae, pollutant spills or uncommon weather patterns.

Because mass mortalities are unexpected events it is important to record as much information as possible at the site and surrounding area, and report the incident to the appropriate management authority (e.g. local council, Parks and Wildlife Service, Environment Division or Marine Resources Division of State Government).

Procedures for reporting mass mortalities

- Take photographs of the dead animals and the area affected.
- Record the location and estimated size of the area affected.
- Record the date and time of assessment.
- Count or estimate the number of dead animals of each species present and record their size. If there are large numbers of dead animals, measure off

approximately five smaller areas and count the number of dead animals of each species in each area. Take the average of these counts and extrapolate to the total affected area to estimate the total number of mortalities.

- Record the presence of other animals in the area, including sick or dying animals and any with skin lesions or wounds.
- Record the presence of any unusual materials in the area, such as oils slicks, discoloured water, rubbish etc. and any activities occurring in the vicinity of the kills.
- If you have the equipment, record temperature, salinity, dissolved oxygen, pH and take a water sample in a clean plastic bottle for possible subsequent analysis. If appropriate take sediment samples and store in glass jars.
- Collect samples of dying or very recently dead animals for analysis using protective gloves (animal tissue breaks down very quickly after death and rapidly becomes unsuitable for analysis). Store dead fish and small invertebrates in plastic bags and keep on ice or deep freeze if the sample will not be analysed within 24 hr.
- Inspect carefully for tag or banding and notify relevant authority if necessary.

Toxicants: sediment, water column, biota

Toxicants are chemicals that are harmful to the fauna and flora of estuaries and coastal waters. They can be natural but toxic at high concentrations or man-made substances. Toxicants can be in the sediments (e.g. heavy metals in the Derwent River) in the water column (e.g. herbicides and pesticides) or in animal/plant material (e.g. heavy metal concentrations in shellfish or finfish). Some chemical compounds, such as ammonia, are an essential component of biological processes but become toxic when concentrated.

Measurement of toxicant concentrations generally requires sophisticated equipment which is available in only a few laboratories. It is also usually expensive to measure, hence is generally only monitored when there is a specific reason to do so. A systematic approach is required where potential toxicants are identified and the monitoring program carefully designed in terms of where and when to monitor to ensure cost-effectiveness and sufficient data are available to verify changes. Toxicants tend to combine with fine sediments and so are often concentrated in depositional areas such as in central basins, seagrass beds or intertidal mud flats.

Monitoring toxicants in the water column can be difficult because many toxicants such herbicides and pesticides are harmful at extremely low concentrations which are difficult to detect in constantly flowing water. However, a new technique being developed by the University of Queensland uses membrane filters which can accumulate toxicants over a period of approximately one month. Heavy metals in oyster meats are currently monitored approximately every three years in oyster farming areas by the Tasmanian Shellfish Quality Assurance Program (TSQAP).

Measurement of toxicants in biota that accumulate these contaminants over time can be a useful means of detecting concentrations that are too low to be measured in water. However, toxicants in animals only record the biologically available fraction of that contaminant. Mussels, oysters and seabird eggs have been commonly used for assessing toxicant levels in a water body over time. Any species used for toxicant analysis should be widespread and common.

Because many toxicants are relatively new synthetic chemicals, it is often difficult to define precise levels at which they are harmful; hence instead of using absolute concentrations, trends over time are often evaluated. Data are compared with baseline or historical values. However, because laboratory techniques for measuring chemicals are becoming increasingly sophisticated, data collected from ten or more years ago may not be comparable with present day measurements.

When measuring toxicants in the sediment, the water column or animals and plants, it is generally recommended that a biological condition indicator is also monitored, such as animal mortalities or occurrence of imposex. However, the effects of toxicants can be subtle, such as reduced reproductive capacity or slower growth, and in certain circumstances more detailed biological measures may be required.

Most toxicants can be tested at the Analytical Services Tasmania Laboratories. However, sometimes there are long waiting periods and we will investigate other testing laboratories in Vic. and NSW.

Pathogens

Pathogens are organisms such as bacteria, viruses, protozoans or fungi that cause disease in human and estuarine/marine organisms. Exposure to pathogens can occur in several ways, either directly through physical contact or indirectly through consumption of contaminated organisms such as shellfish.

It is not possible to monitor all pathogens so total coliforms, thermotolerant coliform bacteria, *E. coli*, and *enterococci* are used as indicators of pathogens. The main sources of pathogens are from warm-blooded animals, including humans, which can be concentrated in sewage and storm water overflows, and in areas receiving animal wastes, such as downstream of intensive dairy farming. Faecal coliforms are an indicator of excrement in an estuary and increasing concentrations generally indicate increasing pollution levels, including more potentially dangerous pathogens such as *Giardia* and *Cryptosporidium*. Thermotolerant coliforms are commonly measured for assessment of recreational water quality. However, new recreational water standards are soon to be introduced and these use concentrations of Enterococci as they have been deemed to be better indicators of sewage pollution in marine waters.

In Tasmania the two main sources of information on pathogens has been through (i) Tasmanian Shellfish Quality Assurance Program (TSQAP), which has been monitoring thermotolerant coliforms in shellfish growing waters for many years to assess whether the shellfish are safe for human consumption, and (ii) local councils who monitor recreational beaches for primary contact, especially over the warmer months.

These assessments of pathogens are generally conducted on water samples sent to NATA registered laboratories. Unlike most other environmental variables, testing for pathogens in estuarine waters is the same as that used in freshwater. Water samples for bacterial analysis must be collected in sterile containers, with an air gap, packed on ice and delivered to the testing laboratory within 24 hours. Bacterial testing is not reliable in turbid waters. The two NATA accredited laboratories for pathogen testing in Tasmania are the Public Health Laboratory at the Royal Hobart Hospital in Hobart and Tasmanian Laboratory Services, 37 Frederick Street, Launceston Tasmania, (www.taslab.com.au).

Approximate costs for analysis are:

\$34.50 *E. coli* and thermotolerant coliforms

\$31.50 thermotolerant coliforms

\$43.50 Enterococci in beaches (via enterolert) and \$72 environmental waters

The Waterwatch Australia National Technical Manual Module 7, Estuarine Monitoring, (2006) describes test kits for bacterial analysis which are available commercially. These include presence-absence kits and plating for counts of bacteria. The Waterwatch Tasmania – Equipment guide 2003 describes and provides prices for an easy method for identification and counting general coliform and *E. coli* colonies. It also describes the membrane filtration method which allows accurate counts of low numbers of faecal bacteria.

A new product B2PTM on the market suitable for bacterial testing by community groups enables testing to be conducted on the spot. The water sample jars contain chemicals which specifically test for coliforms and *E. coli* and the rate of change of colour of the sample solution is related to the concentration of bacteria. This product is available from scientific suppliers and costs \$25 per sample container. A similar product is available for testing coliforms and *E. coli* in foods, including shellfish; cost approx \$30 per sample.

Note that the sites monitored and default trigger values for pathogens are in relation to human health risk and not environmental risk.

Shoreline Position

Sediments naturally move around an estuary or on the open coast as a result of water currents and wave action, depending on the geology and topography of each region. However, many human activities markedly affect sedimentation and erosion rates, including land clearing, land reclamation, dredging, and construction of jetties and other artificial structures in the estuarine environment. Altered sedimentation and erosion rates can result in a change to the function of an estuary or coastal waters by changing the position of shorelines, filling in channels, smothering and removing habitats and benthic communities and increasing turbidity levels. Shoreline positions are also likely to change as a result of climate change and global warming.

The Tasmanian Shoreline Monitoring and ARChiving project (TASMARC) has been developed to provide information on shoreline movement of a selected group of Tasmanian beaches through measurement of (i) high water mark and (ii) beach profile. The methodology is explained at the website <http://staff.acecrc.org.au/~johnubter/tasmarc.pdf>, and has been developed for community groups.

An indicator of sediment movement in estuaries is currently being developed and details will be provided later.

Litter

Litter or marine debris is primarily an indicator for community monitoring. It is more an indicator of shameful human activity than estuarine health *per se*. Litter not only spoils the amenity of an area but can also cause animal deaths, degradation of the habitat and is potentially harmful to the community via sharp objects and health risks. The sources of litter include from boats, stormwater, direct dumping and windblown.

Sites selected for litter monitoring should be readily accessible at all times to allow regular monitoring, a site where litter accumulates and not subject to cleaning operations.

Equipment list:

- GPS or topographic map
- 100 m measuring tape or trundle wheel
- Data sheets, clipboards and pencils
- Digital camera
- Appropriate clothing (heavy duty gloves and protective shoes)
- Heavy duty plastic bags
- Special container for sharps
- Scales accurate to 0.1 kg

The recommended procedure for regular monitoring of litter and to enable comparisons over time is as follows:

At each site set up a transect line using the tape measure or trundle wheel from the low tide mark to the top of the beach. Record location using GPS and length of transect. Photograph along the transect line. Collect all visible litter within 5 m either side of the transect. Sort all litter collected into categories, such as glass, cans, plastic bottles, plastic bags, other plastics, rope, paper and cardboard, fabrics and footwear, metal, cigarette butts, and miscellaneous. Count the number of items in each category. Remove sand and fouling from the waste and weigh each category. Repeat this transect twice at each site (average of 3 transects).

Water Quality Guideline Levels

The relevant guidelines for water quality monitoring developed by the Australian and New Zealand Environment and Conservation Council (2000) are in part summarised below (Table 2). These are the default trigger values in the absence of site specific levels that can be used to evaluate the protection of different aquatic ecosystems across Australia. However, these values were ascertained without using Tasmanian estuarine or marine data – thus a precautionary approach should be adopted when applying these default trigger values in Tasmania.

Examples of water quality data recorded in Tasmanian estuaries and coastal waters are provided in the following tables. These can be used as a general guide for the range of values that can be expected in Tasmania. Table 3 from Murphy *et al* (2003) lists values for selected water quality parameters from 22 estuaries around Tasmania. Using this information they developed draft indicator levels for turbidity, chlorophyll-a, nitrates and phosphates for Tasmanian estuaries. An example of the difference in nutrient levels that can occur between normal sampling and flood events is given in Table 4 for the Little Swanport estuary. Table 5 shows ammonium, nitrate+nitrite and phosphate values in the Huon estuary in 1996-98 and 2002 - 2003, and in the D'Entrecasteaux Channel in 2002 – April 2003.

Table 2. ANZECC WATER QUALITY GUIDELINES – AQUATIC ECOSYSTEMS

		TP	FRP	TN	NO _x	NH ₄ ⁺	DO (% saturation)		pH	
	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	µg L ⁻¹	Lower limit	Upper limit	Lower limit	Upper limit
Upland River	NA	13	5	480	190	13	90	110	6.5	7.5
Lowland River	5	50	20	500	40	20	85	110	6.5	8.0
Estuaries ^a	4	30	5	300	15	15	80	110	7.0	8.5
Marine	1	25	10	120	5	15	90	110	8.0	8.4

a = These values were ascertained without using Tasmanian estuarine or marine data – a precautionary approach should be adopted when applying these default trigger values.

Table 2 (continued). ANZECC WATER QUALITY GUIDELINES – AQUATIC ECOSYSTEMS

METALS and METALLOIDS	Trigger values for freshwater ($\mu\text{g L}^{-1}$)				Trigger values for marine water ($\mu\text{g L}^{-1}$)			
	Level of protection (% species)				Level of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
Aluminium pH >6.5	27	55	880	150	ID	ID	ID	ID
Aluminium pH <6.5	ID	ID	ID	ID	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360	ID	ID	ID	ID
Cadmium	0.06	0.2	0.4	0.8	0.7	5.5	14	36
Chromium (Cr III)	ID	ID	ID	ID	7.7	27.4	48.6	90.6
Chromium (Cr VI)	0.01	1.0	6	40	0.14	4.4	20	85
Cobalt	ID	ID	ID	ID	0.0005	1	14	150
Copper	1.0	1.4	1.8	2.5	0.3	1.3	3	8
Iron	ID	ID	ID	ID	ID	ID	ID	ID
Lead	1.0	3.4	5.6	9.4	2.2	4.4	6.6	12
Manganese	1200	1900	2500	3600	ID	ID	ID	ID
Mercury	0.06	0.6	1.9	5.4	0.1	0.4	0.7	1.4
Nickel	8	11	13	17	7	70	200	560
Silver	0.02	0.05	0.1	0.2	0.8	1.4	1.8	2.6
Tin	ID	ID	ID	ID	ID	ID	ID	ID
Tributyltin	ID	ID	ID	ID	0.0004	0.006	0.02	0.05
Zinc	2.4	8.0	15	31	7	15	23	45

PESTICIDES and HERBICIDES	Trigger values for freshwater ($\mu\text{g L}^{-1}$)				Trigger values for marine water ($\mu\text{g L}^{-1}$)			
	Level of protection (% species)				Levels of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
2,4-D	140	280	450	830	ID	ID	ID	ID
Atrazine	0.7	13	45	150	ID	ID	ID	ID
Chlorpyrifos	0.00004	0.01	0.11	1.2	0.0005	0.009	0.04	0.3
Fenitrothion	0.1	0.2	0.3	0.4	ID	ID	ID	ID
Glyphosate	370	1200	2000	3600	ID	ID	ID	ID
Hexazinone	ID	ID	ID	ID	ID	ID	ID	ID
MCPA	ID	ID	ID	ID	ID	ID	ID	ID
Metsulfuron	ID	ID	ID	ID	ID	ID	ID	ID
Simazine	0.2	3.2	11	35	ID	ID	ID	ID

ID = Insufficient data to derive a high reliability trigger value.

Indicative interim working levels may have been determined in ANZECC guidelines for some of these IDs but contextual understanding of the IWL is required when using them so reference should be made to ANZECC guidelines.

Table 3. Average turbidity (NTU), chlorophyll-a, NO_x and PO₄ concentrations ($\mu\text{g l}^{-1}$) and yearly median value for each estuary, by bioregion and sampling event, July 1999 to June 2000 (Murphy *et al* 2003).

Bioregion	Estuary	Parameter	Sample						median (JA99-MJ00)
			JA99	SO99	ND99	JF00	MA00	MJ00	
Boags	Duck Bay	Turbidity	21.0	17.6	7.0	8.7	6.0	12.2	8.3
		Chlorophyll a	2.9	2.0	1.4	1.4	1.5	1.7	1.5
		NO _x	289	268	165	39	93	235	127
		PO ₄	104	30	27	30	17	15	28
	East Inlet	Turbidity	2.1	2.8	1.1	1.9	0.9	1.7	1.7
		Chlorophyll a	0.1	0.0	4.4	0.6	0.0	0.2	0.0
		NO _x	5	3	1	1	2	3	2
		PO ₄	20	12	8	10	11	11	11
	Black River	Turbidity	8.9	3.9	3.8	3.0	2.9	3.1	3.4
		Chlorophyll a	0.2	0.1	0.8	0.9	0.7	0.2	0.4
		NO _x	95	62	48	24	48	55	57
		PO ₄	5	6	3	9	5	1	4
	Don River	Turbidity	50.0	9.8	125.3	no data	8.1	4.5	8.6
		Chlorophyll a	2.5	0.7	25.6	17.6	0.7	0.1	0.8
		NO _x	1125	328	20	5	31	343	118
		PO ₄	8	4	31	11	13	8	9
	Mersey River	Turbidity	12.0	3.6	13.3	no data	6.3	3.1	5.5
		Chlorophyll a	0.8	0.3	3.1	0.9	0.7	0.2	0.5
		NO _x	289	65	19	24	22	61	31
		PO ₄	8	8	9	15	13	10	11
	Port Sorell	Turbidity	39.9	6.6	5.4	no data	4.8	3.1	5.4
		Chlorophyll a	1.3	1.2	1.6	0.9	0.5	0.3	0.8
		NO _x	217	5	0	2	4	11	4
		PO ₄	12	22	9	8	9	6	8
	Boobyalla Inlet	Turbidity	16.9	13.2	4.2	4.5	4.2	8.2	6.9
		Chlorophyll a	1.7	1.4	0.8	4.1	1.1	0.8	1.2
		NO _x	250	277	132	72	18	158	138
		PO ₄	9	6	1	2	3	2	2
	Little Musselroe River	Turbidity	4.0	5.4	1.6	6.7	3.5	3.9	3.4
		Chlorophyll a	1.6	0.6	0.0	33.2	2.5	2.0	1.1
		NO _x	16	24	1	2	1	13	4
		PO ₄	8	7	4	17	4	6	6
Freydinet	Ansons Bay	Turbidity	1.4	2.6	1.8	5.3	1.7	0.8	1.7
		Chlorophyll a	20.3	8.8	5.7	11.2	7.5	2.2	5.3
		NO _x	5	4	1	14	2	3	2
		PO ₄	10	6	3	10	14	12	8
	Grants Lagoon	Turbidity	1.2	1.3	2.7	2.2	1.7	1.2	1.5
		Chlorophyll a	1.3	1.0	0.4	3.0	1.2	0.8	1.2
		NO _x	17	3	0	1	2	38	1
		PO ₄	4	2	3	3	2	2	2
	Douglas River	Turbidity	8.0	1.4	1.6	2.1	1.4	2.1	1.7
		Chlorophyll a	0.1	1.0	0.7	0.0	0.3	0.0	0.0
		NO _x	11	0	11	178	75	62	24
		PO ₄	1	2	2	3	2	8	2
	Great Swanport	Turbidity	1.7	1.5	1.6	1.5	1.4	1.8	1.4
		Chlorophyll a	0.3	0.4	0.1	0.9	0.6	1.0	0.5
		NO _x	0	2	0	2	1	0	1
		PO ₄	6	3	2	4	5	2	3
	Meredith River	Turbidity	14.8	0.9	2.5	3.4	3.5	0.9	2.6
		Chlorophyll a	6.0	2.2	8.8	3.2	10.0	0.8	1.9
		NO _x	124	6	1	56	3	6	6
		PO ₄	5	2	3	6	4	2	2
	Little Swanport	Turbidity	1.8	1.5	2.1	2.3	3.3	2.1	1.8
		Chlorophyll a	0.7	0.3	1.2	2.4	6.1	1.1	1.1
		NO _x	3	1	0	0	0	2	0
		PO ₄	6	4	3	3	5	4	4
	Earlham Lagoon	Turbidity	3.7	1.8	2.0	2.1	3.0	0.9	2.0
		Chlorophyll a	0.9	0.2	0.5	0.8	0.6	0.1	0.4
		NO _x	28	1	1	5	1	2	2
		PO ₄	9	6	6	5	6	6	6
Bruny	Browns River	Turbidity	56.0	1.8	3.9	5.0	5.1	3.1	3.2
		Chlorophyll a	2.4	0.7	2.5	7.0	9.2	4.7	2.6
		NO _x	332	8	3	1	1	10	5
		PO ₄	8	14	25	13	42	17	16
	Cloudy Bay Lagoon	Turbidity	1.2	0.9	1.4	1.1	1.0	1.4	1.0
		Chlorophyll a	2.3	0.9	0.3	0.9	0.6	1.0	0.7
Davey	Catamaran River	NO _x	7	4	0	2	1	13	1
		PO ₄	6	4	5	9	5	9	6
	Cockle Creek	Turbidity	3.1	1.2	1.2	2.0	1.1	2.0	1.5
		Chlorophyll a	0.0	0.6	0.5	0.1	0.1	0.0	0.0
		NO _x	13	9	0	1	6	9	5
		PO ₄	4	7	5	5	5	4	5
Franklin	Pleasant River	Turbidity	3.5	1.0	1.3	1.3	1.6	1.5	1.4
		Chlorophyll a	0.7	1.2	0.6	0.1	1.1	0.8	0.4
		NO _x	22	5	1	1	1	7	2
		PO ₄	5	7	2	4	3	3	4
	Nelson Bay River	Turbidity	2.9	9.8	1.8	1.6	4.6	2.6	2.6
		Chlorophyll a	0.0	0.0	0.0	0.1	0.2	0.0	0.0
		NO _x	28	22	36	20	21	19	23
		PO ₄	1	0	0	2	0	0	0
	Arthur River	Turbidity	6.2	10.7	5.9	4.2	1.3	3.1	5.2
		Chlorophyll a	0.0	0.1	0.0	3.4	1.5	0.0	0.0
		NO _x	13	7	8	2	3	8	7
		PO ₄	2	1	1	8	5	2	2
		Turbidity	10.5	5.2	8.2	2.5	2.9	4.3	4.5
		Chlorophyll a	0.0	0.1	0.0	0.6	0.1	0.0	0.0
		NO _x	39	17	10	5	9	20	13
		PO ₄	3	1	1	2	0	1	1

Draft (indicator levels)		low	medium	high	very high
Turbidity	NTU	0 to 4	4.1 to 10	10.1 to 20	> 20
Chlorophyll a	$\mu\text{g/L}$	0 to 2	2.1 to 5	5.1 to 10	> 10
NO _x	$\mu\text{g/L}$	0 to 20	21 to 50	51 to 100	> 100
PO ₄	$\mu\text{g/L}$	0 to 5	6 to 15	16 to 30	> 30

Table 4. Water quality values from Little Swanport January 2004 – February 2005 for monthly sampling and flood events (Crawford *et al* 2006) .

WATER QUALITY MEASUREMENTS ($\mu\text{g.l}^{-1}$)	Estuarine (all sites)	Marine (A – deep)	ANZECC estuarine/marine
NOX			
Monthly samples	2 - 42	2 - 25	15 / 5
Flood events	189 - 293	17 - 48	
NH₄			
Monthly samples	8 - 24	7 - 20	15/ 15
Flood events	37 - 150	14 - 39	
PO₄			
Monthly samples	2 - 5	3 - 8	5 / 10
Flood events	5 - 6	3 - 7	

Table 5. Ammonium, NOX (nitrate + nitrite) and phosphate values in the Huon estuary in 1996-98 (CSIRO HES study team, 2000) and 2002 - 2003, and in the D'Entrecasteaux Channel in 2002 – April 2003 (Crawford, unpublished data).

WATER QUALITY MEASUREMENTS ($\mu\text{g.l}^{-1}$)	Riverine	Estuarine (all sites)	Marine	ANZECC river/est/marine
NO_x HES	<0.7 – 9.8	<0.7 – 101	<0.7 – 74	– / 15 / 5
Huon 2002 - 2003		0 – 81	0 – 72	
Channel 2002 - 2003			0 – 157	
NH₄ HES	0.7 – 2	<0.3 – 36.4	0.84 – 14	– / 15 / 15
Huon 2002 - 2003		0 – 34	2 – 33.6	
Channel 2002 - 2003			0 – 54	
PO₄ HES	<0.93 – 2.8	<0.93 – 22	5.6 – 19.8	– / 5 / 10
Huon 2002 - 2003		0 - 17	0 – 20.2	
Channel 2002 - 2003			2.2 – 22	

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